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Front observer for data assimilation of electroanatomical mapping data for a numerical atrial model

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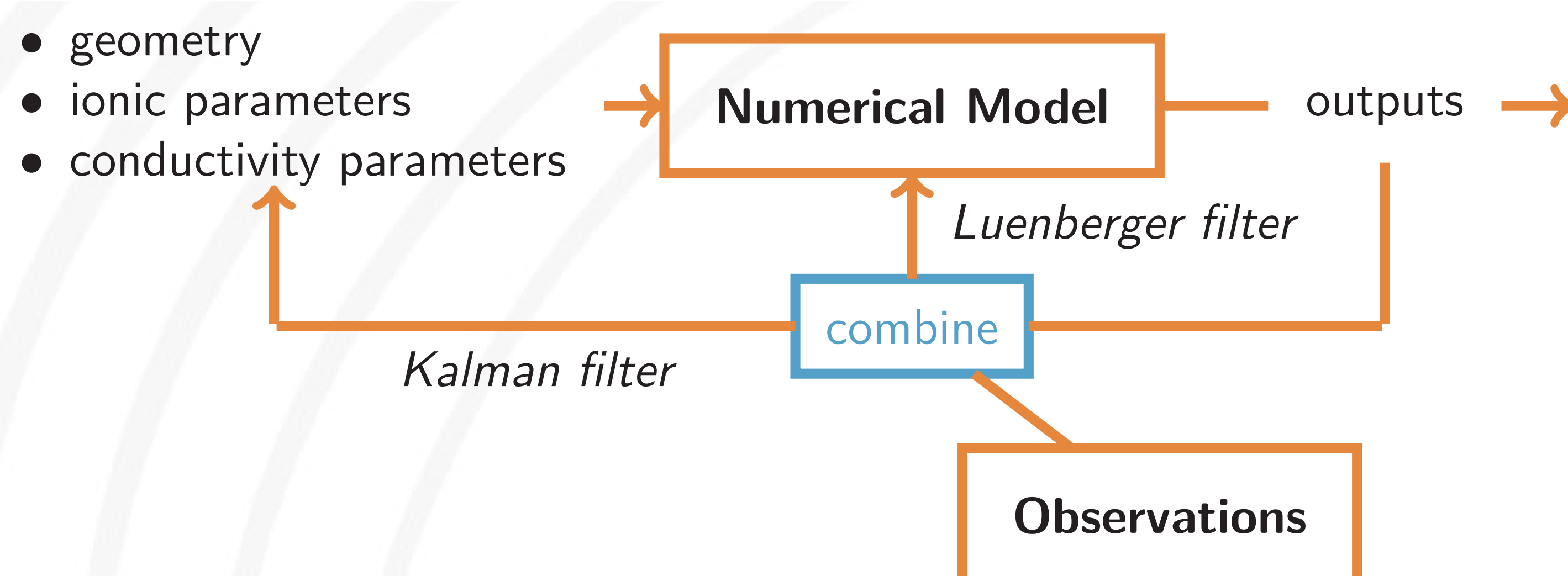
Introduction

In this study, we aim at developing a method to fit an atrial numerical model to some patient's data. We want to use *data assimilation techniques* therefore.

The bilayer model of the atria from [1] provides a good basis. Our objective is to adjust it to data from electroanatomical maps of any patient, in the most automatic way.

Data assimilation provides a natural way to combine a numerical model and incomplete observations.

Principle of data assimilation



The model is based on the geometry and structure, from MR images and from our current knowledge (e.g fibre directions, and conduction parameters). It is complemented with a priori ionic parameters.

The outputs of the model are compared to some given observations (any electrical data), so as to *minimize a distance between the model and the observation*.

The model is modified accordingly, and provides new outputs...

Method: a Luenberger observer

We introduce a Luenberger observer of the propagation in a surface atrial model, like in [2]. The observer can pursue the actual activation front reconstructed from the observations.

It amounts to add a term in the bilayer model which compares the state of the model with the available observations, *only on the endocardial layer*, as follows:

$$\underbrace{\lambda \delta(\Gamma_u, x) dJ(u)}_{\text{error on the shape}} + \underbrace{\mu (1 + \text{sign}(dJ(u)(u - c_{th}))) dJ(u)}_{\text{error on the topology}}.$$

- The coefficients $\lambda \geq 0$ and $\mu \geq 0$ (called "gain") are set arbitrarily.
- The error is measured with the quantity

$$J(u) := \int_{\Omega_u^{in}} (z - C_1(\Omega_u^{in}))^2 d\Omega + \int_{\Omega \setminus \Omega_u^{in}} (z - C_2(\Omega_u^{in}))^2 d\Omega,$$

defined such that

The observation and the data match $\Leftrightarrow J(u) = 0$.

- The domain Ω_u^{in} is the region depolarized at time $t > 0$ in the model;
- The function z denotes the observation, and the numbers C_k are given by

$$C_1(\Omega_u^{in}) = \frac{\int_{\Omega_u^{in}} z dx}{\int_{\Omega_u^{in}} dx}, \quad C_2(\Omega_u^{in}) = \frac{\int_{\Omega \setminus \Omega_u^{in}} z dx}{\int_{\Omega \setminus \Omega_u^{in}} dx}.$$

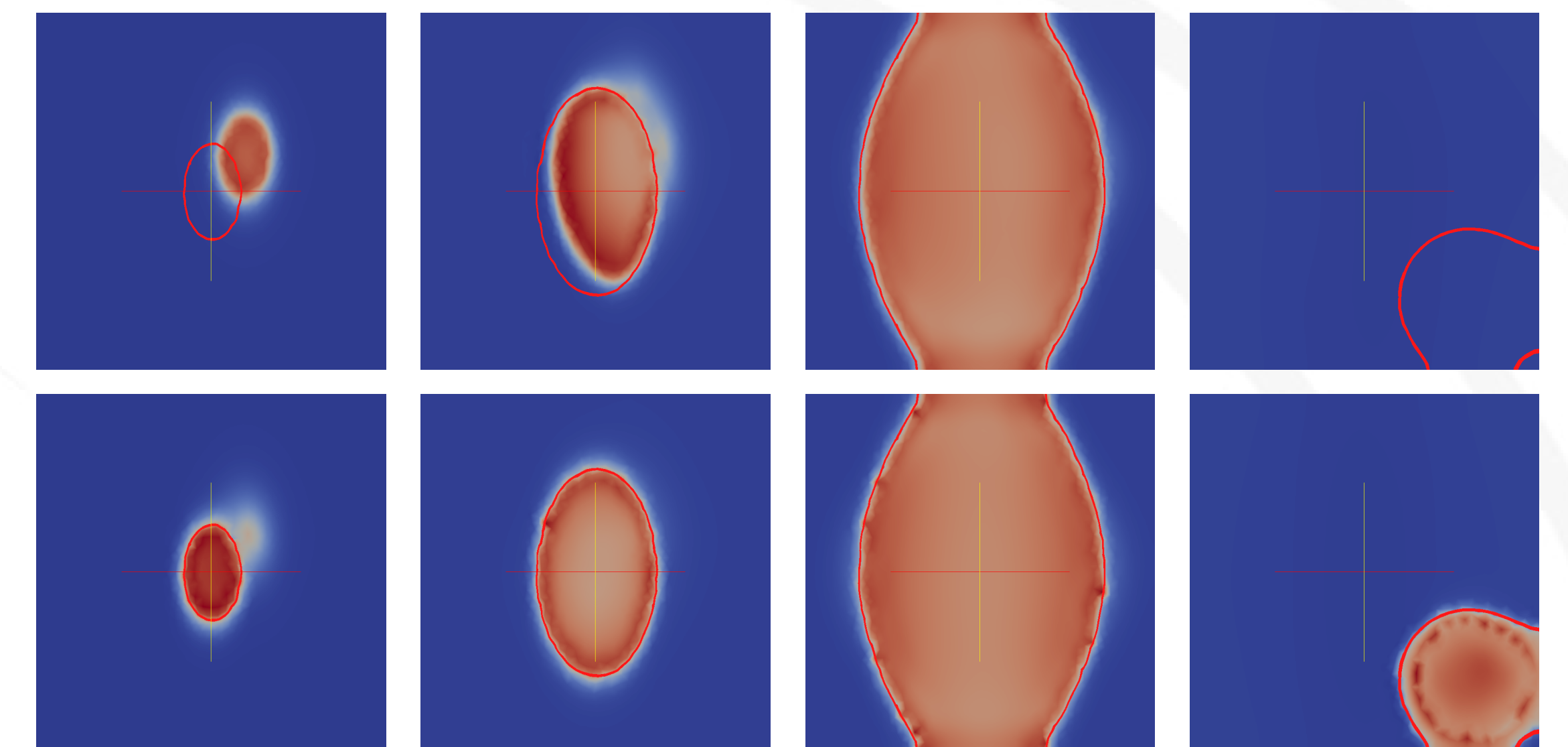
The error on the shape correct the location of the activation front.

The error on the topology track any breakthrough of an new activation site.

Test case 1: in-silico data

An activation map is build from a numerical model with 2 sites of excitation (center at time $t = 0$ and lower right corner at $t = 250$ ms).

The model is run with a single excitation at a wrong location, shifted upper right, see top left image on the figure below.

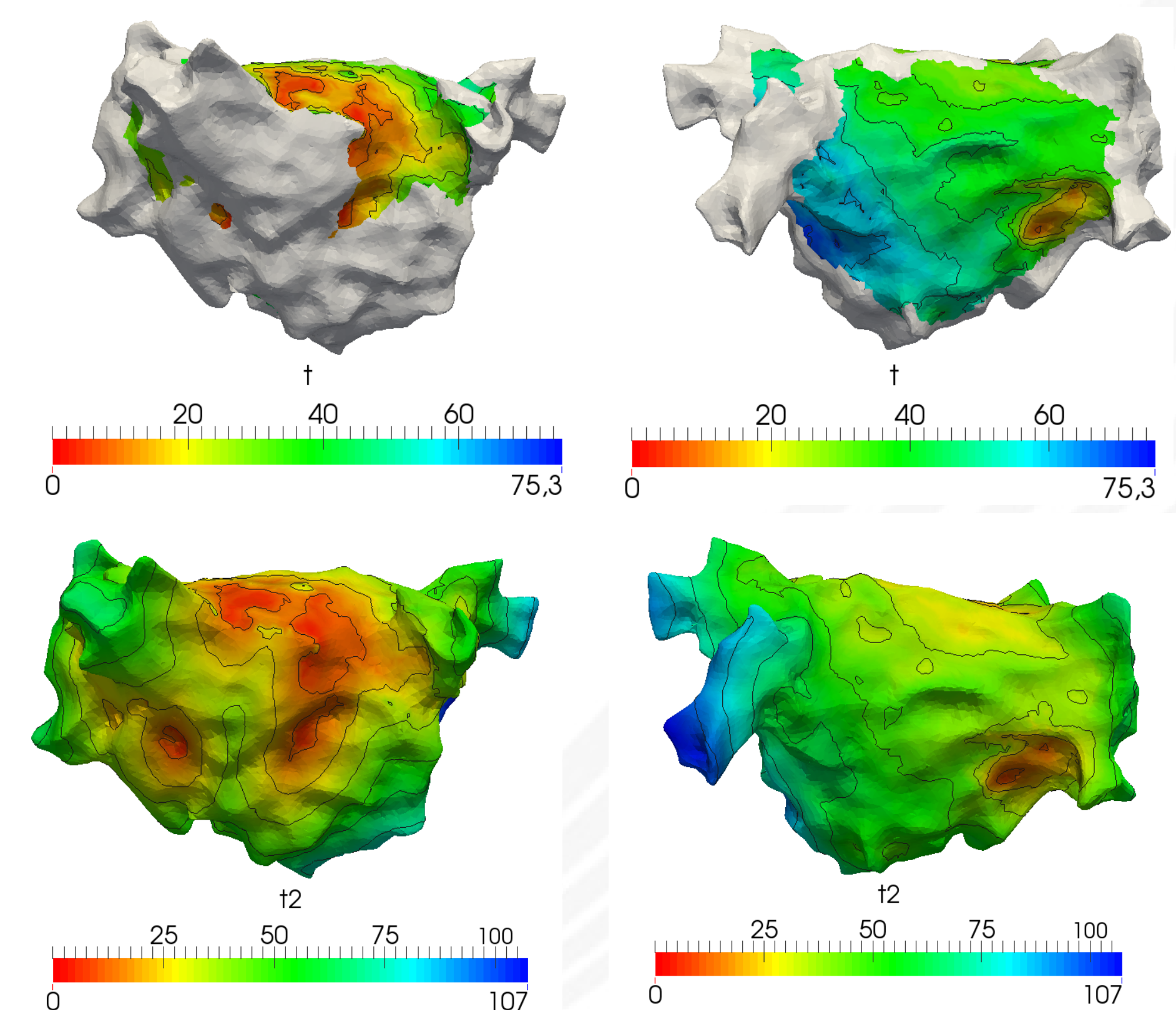


- From left to right: the action potential (red=depolarized, blue=resting state) at times $t = 5, 8, 13, 265$ ms;
- The red line shows the measured (in-silico) activation front;
- Top row: the model corrected only by the error on the shape;
- Bottom row: the model corrected by both errors.

A breakthrough at any time can be captured by the model.

Test case 2: a patient's data

This work is in progress, but we could run the model with the observer on both errors for a dataset acquired during a CARTO procedure for a patient with AF.



- Top row: activation map reconstructed from CARTO's LAT.
- Bottom row: activation map completed by data assimilation.

The mean and standard deviation of the difference between the observation and the data are, respectively, 0.63 ms and 0.97 ms.

Conclusion and future works

Our model can track an activation front from observed data, including breakthrough of wavefront at any time.

We have to incorporate a Kalman filter, in order to recover ionic and conduction parameters in the model. In addition, other quantities may be easily build with the model: phase maps, velocity fields, repolarization properties...

[1] Simon Labarthe, Jason Bayer, Yves Coudière, Jacques Henry, Hubert Cochet, Pierre Jaïs, and Edward Vigmond. A bilayer model of human atria: mathematical background, construction, and assessment. *Europace*, 16(suppl 4):iv21–iv29, 2014.

[2] A Collin, D Chapelle, and P Moireau. Sequential state estimation for electrophysiology models with front level-set data using topological gradient derivations. In *Functional Imaging and Modeling of the Heart*, pages 402–411. Springer, 2015.